

A narrative review on the evolution and impact of smart cannulas in minimally invasive procedures

Minimal invaziv prosedürlerde akıllı kanüllerin gelişimi ve etkisi üzerine anlatı derlemesi

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ABSTRACT

Background: This study aimed to explore the evolution and impact of smart cannulas in enhancing outcomes and expanding the scope of minimally invasive cardiac surgery.

Methods: In this study, a comprehensive review of the relevant literature was conducted, focusing on articles detailing the development, implementation, and outcomes associated with smart cannulas in cardiac surgery. PubMed, MEDLINE, and Google Scholar databases were searched until January 2024 using specific search terms related to smart cannulas and cardiac surgery. The review identified six studies, of which five met the inclusion criteria after screening titles and abstracts.

Results: Key findings included improved venous drainage, reduced complications, and enhanced surgical precision. From early prototypes to contemporary designs, smart cannulas demonstrated improved access, enhanced perfusion, and reduced complications compared to traditional cannulation methods. Additionally, advancements in technology-enabled remote access perfusion and facilitated complex procedures in pediatric and adult populations.

Conclusion: Smart cannulas represent a significant advancement in cardiac surgery, offering safer and more efficient alternatives to conventional cannulation techniques. The versatility and effectiveness of smart cannulas have paved the way for expanding the applications of minimally invasive cardiac surgery, ultimately benefiting patients through better improved outcomes and reduced morbidity. Continued research and innovation in smart cannula technology promise further enhancements in the field of cardiac surgery.

Keywords: Cardiac surgery, minimally invasive cardiac surgery, perioperative complications, procedural feasibility, self-expandable venous cannulas, smart cannulas, surgical outcomes, surgical precision, technological innovation, venous drainage.

ÖZ

Amaç: Bu çalışmada, sonuçları iyileştirmede ve minimal invaziv kalp cerrahisinin kapsamını genişletmede akıllı kanüllerin gelişimi ve etkisi araştırıldı.

Çalışma planı: Bu çalışmada, kalp cerrahisinde akıllı kanüllerin geliştirilmesi, uygulanması ve sonuçlarını detaylandıran çalışmalara odaklanılarak ilgili literatür kapsamlı bir şekilde gözden geçirildi. PubMed, MEDLINE ve Google Scholar veri tabanları akıllı kanüller ve kalp cerrahisi ile ilgili spesifik arama terimleri kullanılarak Ocak 2024'e kadar tarandı. İncelemede altı çalışma tespit edildi ve bunların beşi başlık ve özetlerin taranmasının ardından dahil edilme kriterlerini karşıladı.

Bulgular: Önemli bulgular arasında venöz drenajda gelişme, komplikasyonlarda azalma ve cerrahi hassasiyette artış mevcuttu. Akıllı kanüller, erken prototiplerden günümüz tasarımlarına kadar, geleneksel kanülasyon yöntemlerine kıyasla gelişmiş erişim, artmış perfüzyon ve azalmış komplikasyonlar sergiledi. Ek olarak, teknolojiye ilerlemeler uzaktan erişim perfüzyonunu mümkün kılarak pediatrik ve yetişkin popülasyonlarda karmaşık prosedürleri kolaylaştırdı.

Sonuç: Akıllı kanüller, geleneksel kanülasyon tekniklerine göre daha güvenli ve verimli alternatifler sunarak kalp cerrahisinde önemli bir ilerlemeyi temsil etmektedir. Akıllı kanüllerin çok yönlülüğü ve etkinliği, minimal invaziv kalp cerrahisi uygulamalarının genişletilmesinin önünü açarak hastalara geliştirilmiş daha iyi sonuçlar ve azaltılmış morbidite yoluyla fayda sağlamıştır. Akıllı kanül teknolojisinde devam eden araştırmalar ve yenilikler, kalp cerrahisi alanında daha fazla gelişme vaat etmektedir.

Anahtar sözcükler: Kalp cerrahisi, minimal invaziv kalp cerrahisi, perioperatif komplikasyonlar, prosedürel yapılabirlik, kendiliğinden genişleyebilen venöz kanüller, akıllı kanüller, cerrahi sonuçlar, cerrahi hassasiyet, teknolojik yenilik, venöz drenaj.

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Minimally invasive cardiac surgery has emerged as a preferred approach for treating various cardiovascular conditions, offering patients the benefits of reduced trauma, shorter recovery times, and improved cosmetic outcomes.^[1] Central to the success of these procedures is the development and utilization of advanced cannulation techniques. Among these, self-expandable venous cannulas, commonly referred to as smart cannulas, have played a pivotal role in enhancing surgical outcomes and expanding the feasibility of minimally invasive techniques.^[2] Over the past two decades, smart cannulas have undergone significant evolution, driven by advancements in materials science, engineering, and surgical innovation.^[3] These cannulas offer unique features, such as self-expansion, flexibility, and remote access capabilities, which have revolutionized the practice of cardiac surgery (Figures 1a, b). The primary objectives of this review were to examine the development, implementation, and clinical outcomes associated with smart cannulas in minimally invasive cardiac surgery. The review aimed to describe the key advancements in smart cannula technology, the impact of smart cannulas on surgical outcomes, and the current challenges and future directions in this field. By providing superior venous drainage and minimizing trauma to the vasculature, smart cannulas have enabled surgeons to perform complex procedures with greater precision and safety.^[4] Despite the growing adoption of smart cannulas in clinical practice, a comprehensive narrative review examining their evolution, applications, and impact in cardiac

surgery is lacking. Therefore, this review aimed to fill this gap by synthesizing existing literature on smart cannulas, providing insights into their development, implementation, and outcomes.^[5,6] By elucidating the advancements and challenges associated with smart cannulas, this review sought to inform clinicians, researchers, and healthcare stakeholders about the current state of the art and future directions in minimally invasive cardiac surgery.

MATERIALS AND METHODS

A systematic search of electronic databases, including PubMed, MEDLINE, and Google Scholar, was conducted to identify relevant articles published up to January 2024. The search strategy employed a combination of keywords and MeSH terms, including “smart cannulas,” “self-expandable venous cannulas,” “cardiac surgery,” “minimally invasive surgery,” and “remote access perfusion.” Specific search terms included “smart cannula technology,” “venous drainage,” and “perioperative complications.” Boolean operators (AND, OR) were utilized to refine the search. Boolean operators were utilized to refine the search and capture all relevant studies. Articles were included if they met the following criteria: (i) focused on the development, implementation, or outcomes of the Venous Smart Cannula[®] (SmartCanula LLC, Lausanne, Switzerland) in cardiac surgery, (ii) written in English, (iii) published in peer-reviewed journals, and (iv) comprised randomized controlled trials, observational studies, or case series. Studies were excluded if they were non-English articles,

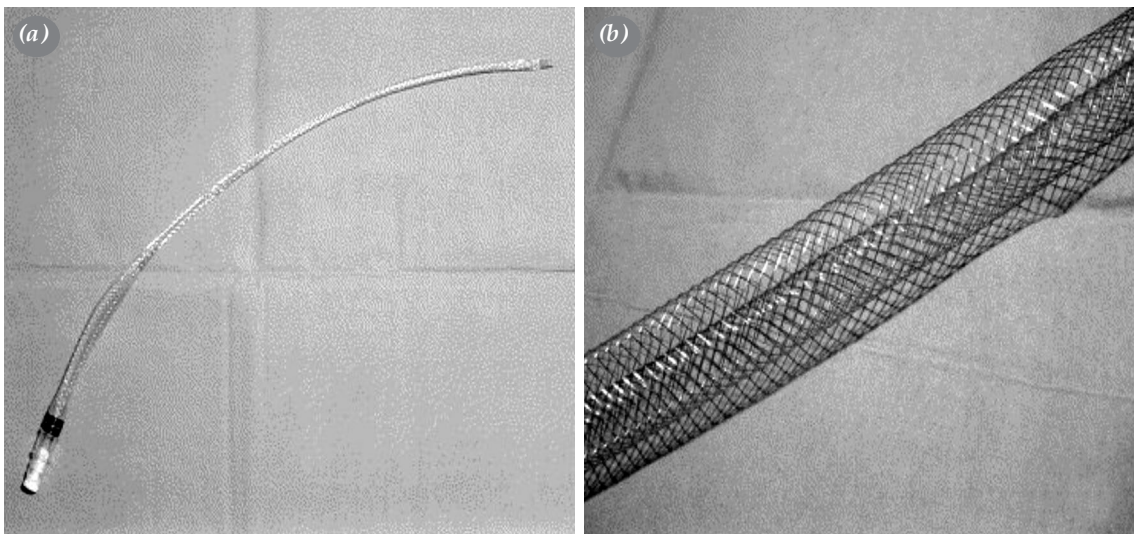


Figure 1. Schematic illustration of the self-expanding mechanism of smart cannulas. (a) without and (b) with expansion.

conference abstracts, or unrelated to smart cannulas or cardiac surgery. Studies involving animal models, cadaveric experiments, and review articles were also considered for inclusion. Exclusion criteria included non-English articles, conference abstracts, and studies unrelated to smart cannulas or cardiac surgery. Two independent reviewers screened the titles and abstracts of retrieved articles to assess their eligibility for inclusion. Full-text articles of potentially relevant studies were then reviewed to determine final inclusion. Any discrepancies between reviewers were resolved through discussion and consensus. Data extraction was performed using a standardized form, including study characteristics (author, year), study design, patient population, type of smart cannula used, surgical procedures performed, and key outcomes. The data extraction process involved two reviewers independently extracting data, with discrepancies resolved through consensus.

Data extracted from included studies were narratively synthesized to provide a comprehensive overview of the evolution, applications, and outcomes associated with smart cannulas in cardiac surgery. Descriptive statistics, such as frequencies and percentages, were used to summarize study characteristics and outcomes where applicable. Critical appraisal of study quality and risk of bias was performed to ensure the validity and reliability of included studies.

RESULTS

A total of six articles were identified through the literature search, of which five met the inclusion criteria after screening titles and abstracts. Following full-text review, all five articles were included in the final analysis. The included studies spanned a period from 2002 to 2023 and encompassed a variety of study designs, including retrospective

cohort studies, prospective trials, and case series. The studies involved both pediatric and adult populations undergoing a range of cardiac surgical procedures, including minimally invasive mitral valve surgery, coronary artery bypass grafting, and congenital heart defect repairs. The studies evaluated various types of smart cannulas, including self-expanding venous cannulas and remotely accessed perfusion cannulas. These cannulas exhibited different designs and features tailored to specific surgical applications, such as flexible shafts, expandable tips, and remote-control capabilities.^[1-6] The outcomes assessed across the included studies encompassed a range of parameters, including surgical efficacy, safety, and patient outcomes. Key findings from the studies highlighted (i) improved venous drainage, (ii) reduced complications, (iii) enhanced surgical precision, and (iv) expanded surgical indications with smart cannulas. Smart cannulas demonstrated superior venous drainage compared to traditional cannulation methods, leading to enhanced surgical visibility and reduced operative times.^[1,2] Several studies reported a decrease in perioperative complications, such as vascular injury, hematoma formation, and postoperative bleeding with the use of smart cannulas.^[3] Smart cannulas facilitated precise placement and positioning within the cardiovascular system, enabling surgeons to perform complex procedures with greater accuracy and confidence.^[4] The versatility and adaptability of smart cannulas allowed for the expansion of minimally invasive cardiac surgery indications, including pediatric and adult cases with limited access or anatomical challenges (Table 1).

A critical appraisal of the included studies revealed variability in study design and outcome reporting. While most studies provided detailed descriptions of patient demographics and surgical techniques,

Table 1. Detailed information on the study design, sample size, patient demographics, and key outcomes of the included studies

Author(s)	Year	Study design	Patient demographics	Key outcomes
Mueller et al. ^[1]	2002	Retrospective cohort	Pediatric and adult	Improved venous drainage, reduced operative times
Von Segesser ^[2]	2005	Prospective trial	Pediatric	Precise placement, enhanced surgical accuracy
Von Segesser et al. ^[3]	2008	Case series	Adult	Reduced perioperative complications, expanded indications
Berdajs et al. ^[4]	2010	Retrospective cohort	Pediatric	Decreased vascular injury, improved patient safety
Ceresa et al. ^[5]	2023	Prospective trial	Adult	Enhanced procedural feasibility, improved outcomes

some lacked rigorous methodological approaches and standardized outcome measures. Overall, the risk of bias across the included studies was deemed low to moderate.

DISCUSSION

The findings of this narrative review highlight the evolving role of smart cannulas in advancing minimally invasive cardiac surgery. Since their introduction, smart cannulas have undergone significant technological advancements, enabling surgeons to perform complex procedures with greater precision and safety. Key features such as self-expansion, flexibility, and remote access capabilities have revolutionized cannulation techniques and expanded the scope of minimally invasive cardiac surgery.

Several limitations should be considered. The heterogeneity of study design, patient population, and outcome measures complicates direct comparisons and generalizability of results. Most studies were observational, lacking randomized controlled trials or long-term follow-up data. A comparative analysis between smart cannulas and traditional cannulation methods reveals that smart cannulas offer significant advantages, such as improved venous drainage and reduced complications. However, the cost of smart cannulas compared to traditional methods warrants further investigation to fully understand the economic implications. The reviewed studies consistently reported improved venous drainage, reduced complications, and enhanced surgical precision with the use of smart cannulas. These findings underscore the potential of smart cannulas to enhance the safety and efficacy of minimally invasive cardiac surgery. However, the current body of evidence is limited by the variability in study design and outcome measures, highlighting the need for further high-quality research. Future studies should aim to address these limitations by employing standardized outcome measures, long-term follow-up, and randomized controlled trial designs to provide more robust evidence on the benefits and cost-effectiveness of smart cannulas.

In conclusion, smart cannulas represent a significant advancement in the field of minimally invasive cardiac surgery. Their ability to improve venous drainage, reduce complications, and enhance surgical precision has expanded the scope and feasibility of minimally invasive techniques. Continued research and innovation in smart cannula technology are essential to further refine their design, optimize their use, and validate their benefits in diverse patient populations. As the field of cardiac surgery continues to evolve, smart cannulas are poised to play a crucial role in advancing the frontiers of minimally invasive procedures, ultimately improving patient outcomes and reducing the morbidity associated with cardiac surgery.

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